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Performance of underground heat storage system in a double-film-covered greenhouse*

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Abstract: An underground heat storage system in a double-film-covered greenhouse and an adjacent greenhouse without the heat storage system were designed on the basis of plant physiology to reduce the energy consumption in greenhouses. The results indicated that the floor temperature was respectively 5.2 °C, 4.6 °C and 2.0 °C higher than that of the soil in the adjacent reference greenhouse after heat storage in a clear, cloudy and overcast sky in winter. Results showed that the temperature and humidity were feasible for plant growth in the heat saving greenhouse.

Key words: Greenhouse, Underground heat storage system, Performance of heat storage, Energy saving
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INTRODUCTION

Temperature is one of the most important greenhouse climate variables influencing the growth, crop production and product quality of plants. It is a challenge to improve the economic potential by controlling ambient air and soil temperature in greenhouses. However, protected horticulture is an industry with high energy consumption. The UN reported that energy consumption for heating greenhouses amounted to 35% of the production cost (Pan *et al*., 1999). In Europe the energy used for heating and cooling of greenhouse represents approximately 1.5% of the total energy consumption (Santamouris *et al*., 1995; 1996). It is obvious that the cost for heating greenhouses in winter is one of the primary components of the production cost limiting the development and economic potential of protected agriculture.

The underground heat storage system in greenhouses can store much solar energy underground and retrieve it from the floor when needed. This was applied for conditioning greenhouses and livestock buildings with favorable effects on energy saving (Baxter, 1992). However, the storage unit in the existing underground heat storage systems in greenhouses was insulated on the sides and the top but not on the base, so the efficiency of the heat storage system was very low. The poor performance was mainly due to the large heat loss from the uninsulated base of the storage unit (Kurata and Takakura, 1991a; 1991b). In order to reduce energy consumption and to increase the utilization of solar energy, an underground heat storage system in double-film-covered greenhouse was designed. Previous experimental results showed that this heat storage system had a performed well in heat exchange and storage (Wang, 2004).

COMPONENTS

The system consists of an outer greenhouse, an inner greenhouse, a floor, a ventilator, inlet pipes and outlet pipes etc. as shown in Fig.1.

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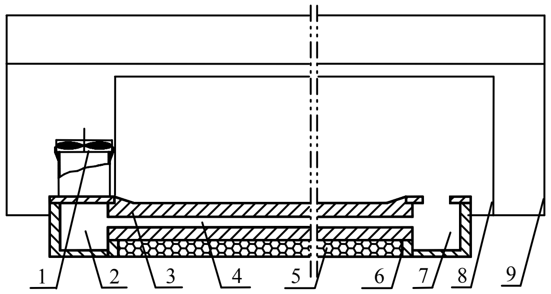

Fig.1 Underground heat storage system in double-film-covered greenhouse

1: Ventilator (diameter: 560 mm); 2: Inlet pipe (30 cm×40 cm); 3: Heat storage layer (thickness: 112 mm); 4: Heat exchanging pipe (diameter: 76 mm); 5: Insulated layer (thickness: 10 cm); 6: Basement layer (thickness: 10 cm); 7: Outlet pipe (30 cm×40 cm); 8: Inner greenhouse; 9: Outer greenhouse

A Hua-dong type greenhouse was used as a protecting outer cover in the experiment for accumulating heat during the day. This greenhouse was a single arc structure width ridge top height of 4.5 m, a shoulder height of 2.5 m, width of 6 m, length of 24 m from east to west, and covered width a 0.08 mm thick polyethylene film. The inner greenhouse with ridge top height of 2 m and width of 6 m increases heat conservation. The floor was composed of a heat storage layer, an insulated layer, a base layer and heat exchanging pipes. The heat storage layer and the basement layer were built up with concrete. A mixture of concrete and cinder was chosen to build the insulate layer. Heat exchanging pipes were set up in the heat storage layer. They had diameter of 76 mm, total length of 18 m and the distance from the center of the pipes to the floor surface was 15 cm. Forty-five pipes were distributed equally over the greenhouse width so their center distance was 133 mm. A ventilator with a flow of 9000 m^3/h and a drive power of 250 W was installed in the air entrance (Wang *et al*., 2003; 2004; 2005a; 2005b).

PRINCIPLE OF HEAT STORAGE

The daytime temperature inside the greenhouse was often very high and even exceeded the limiting values for plant growth due to solar heat accumulation while the temperature of the floor remains lower because the heat is transferred very slowly between the ambient air and the floor. In the system, the ventilator drives the hot air of the greenhouse in the heat exchanging pipes that act as air-to-floor heat exchangers. The excess heat in the air is transferred to the floor by convection during the day and thus decreases the air temperature. The excess heat is stored in the floor simultaneously which increases the floor temperature and the cooler air is returned to the greenhouse. During the night the floor acts as a heat source and the heat transfer from the floor surface to the air is achieved by conduction resulting in increased air temperature.

EXPERIMENTAL METHODS

No plants were grown in the greenhouse in the experiment. During clear and cloudy days, the covering film of the inner greenhouse was opened at 9:00 a.m. and closed at 15:00 p.m. The ventilator started to operate at 10:00 a.m. and stopped at 15:00 p.m. In days with overcast sky, the covering film of the inner greenhouse was opened from 10:00 a.m. to 14:30 p.m. during which the ventilator was running for heat storage. The ventilator never turned at night. Parameters including the ambient air temperature, the humidity and the floor temperature inside the greenhouse with heat storage and the air temperature and soil temperature in the adjacent reference greenhouse as well as the outside air temperature were measured. ZDR-20 temperature sensors and humidity data recorders were installed along the longitudinal center of the inner greenhouse at distance of 1 m, 5 m, 9 m, 13 m and 17 m from the air entrance respectively at a height of 50 cm above the floor (range: temperature –40 °C~100 °C, humidity 0.1%~100% RH; resolution: temperature 0.1 °C, humidity 0.1% RH). At the same time the air temperatures outside and in the adjacent reference greenhouse were also recorded by ZDR-20 sensors. The temperature of only a half floor was measured because the floor was symmetrical and the air flux in the heat exchanging pipes was distributed equally according to Wang *et al*.(2005b). Fig.2 shows the location of the fifteen thermocouples TDW2001 in the floor at depth of 10 cm from the reaching points. The thermocouples were placed between the heat exchange pipes. The floor temperature was recorded at 30-min intervals and so was the soil temperature of the adjacent reference greenhouse.

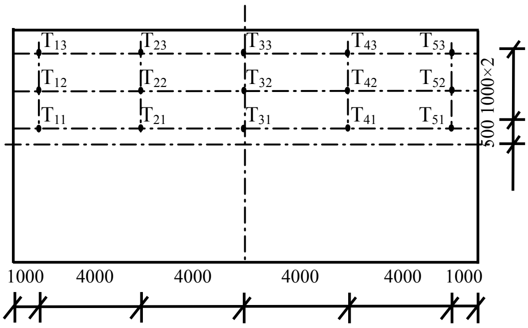

Fig.2 Location of fifteen thermocouples TDW2001 in the floor

RESULTS

The measurements conducted at Zhejiang University, started on January 15 and ended on February 8, 2004. The results from the recorded data showed similarities between the clear, cloudy and overcast sky weather conditions.

Figs.3a and 3b show that the maximum temperature inside the reference greenhouse exceeded 28 °C to 25 °C while the outside temperature was only 10 °C and 12.7 °C in clear and cloudy days respectively. During heat storage, the temperature of the floor increased from 8.3 °C at 10:00 a.m. to 20.3 °C at 3:00 p.m. during the clear day on 2004-01-28 and from 12.9 °C at 10:00 a.m. to 22.1 °C at 3:00 p.m. during the day (2004-01-30) with cloudy sky. Thus an increase of 12 °C to 9.2 °C over 5 h in a clear and cloudy day was realized. The floor temperature was respectively 2.5 °C to 7.5 °C and 3.5 °C to 5.1 °C higher than that of the reference greenhouse. The average temperature difference was 5.2 °C and 4.6 °C respectively. During a day with overcast sky (Fig.3c), the floor temperature increased from 13.1 °C at 10:00 a.m. to 18.4 °C at 2:30 p.m. or 5.3 °C over 4.5 h and 1.6 °C to 3.1 °C higher than that of the adjacent reference greenhouse or an average temperature difference of 2.0 °C. It was obvious that the heat storage system increased the floor temperature significantly. This temperature increase will benefit the substrate of the seedling containers on the warmer floor and so improve plant growth.

As shown in Fig.3, the air temperature inside the heat storage greenhouse in the afternoon was lower than that of the adjacent reference greenhouse because the heat was transferred to the floor. These cooler temperatures are favorable for leaf transpiration and CO_2-uptake.

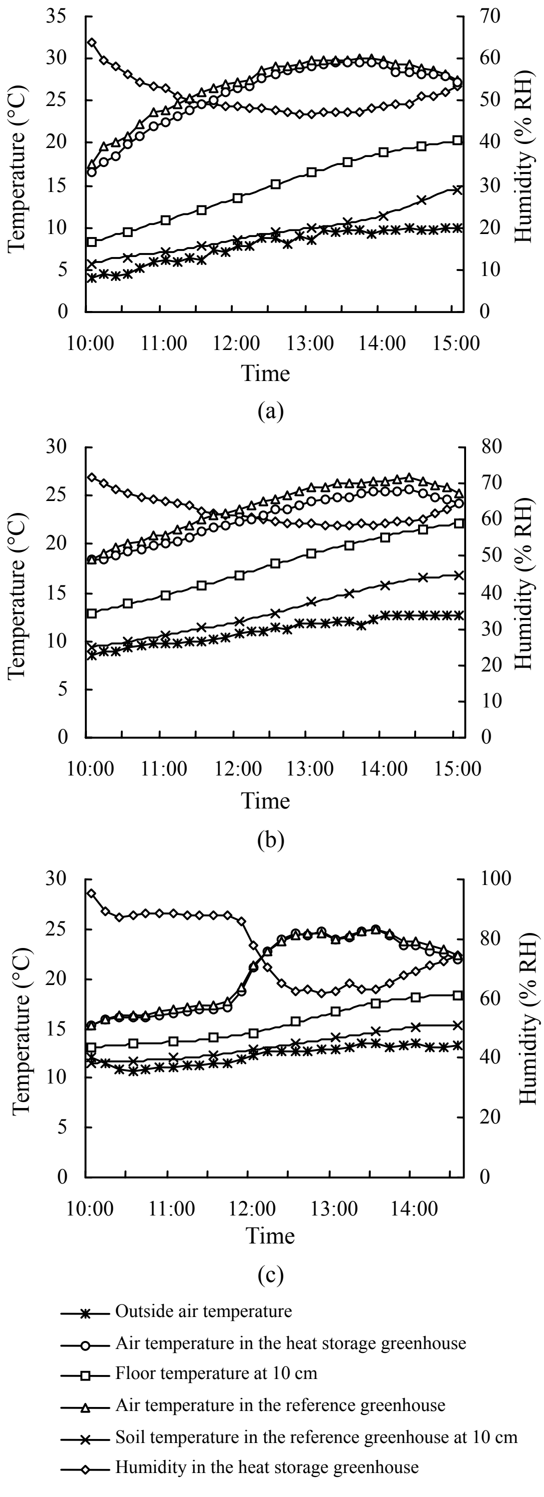

Fig.3 Performance of heat storage (a) on a clear day (2004-01-28), (b) under cloudy sky (2004-01-30) and (c) on overcast day (2004-02-01)

CONCLUSIONS

1. The underground heat storage system in double-film-covered greenhouses is a useful approach for energy saving in greenhouses. At the same time, the solar heat will be stored for overnight use.

2. The heat reduction in the afternoon could benefit the physiological growth conditions (transpiration, CO_2-uptake) of plants in the heat storage greenhouse.

3. During days with clear, cloudy and overcast sky in winter, the floor temperature was respectively increased by 5.2 °C, 4.6 °C and 2 °C compared to the soil in the reference greenhouse. This higher floor temperature will benefit the nursery bed on it and also seedling development.

4. Further research will be undertaken on the relation between the flow of the ventilator and the heat exchange of the system.

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